



Statistical and trend analysis of water quality and quantity data for the Strymon River in Greece

V. Z. Antonopoulos, D. M. Papamichail, K. A. Mitsiou

► To cite this version:

V. Z. Antonopoulos, D. M. Papamichail, K. A. Mitsiou. Statistical and trend analysis of water quality and quantity data for the Strymon River in Greece. *Hydrology and Earth System Sciences Discussions*, 2001, 5 (4), pp.679-692. hal-00304641

HAL Id: hal-00304641

<https://hal.science/hal-00304641>

Submitted on 1 Jan 2001

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Statistical and trend analysis of water quality and quantity data for the Strymon River in Greece

Vassilis Z. Antonopoulos, Dimitris M. Papamichail and Konstantina A. Mitsiou

Depart. of Hydraulics, Soil Science and Agricultural Engineering, School of Agriculture, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece.

Email for corresponding author: vasanton@agro.auth.gr

Abstract

Strymon is a transboundary river of Greece, Bulgaria and Former Yugoslav Republic of Macedonia (FYROM) in southeastern Europe. Water quality parameters and the discharge have been monitored each month just 10 km downstream of the river's entry into Greece. The data of nine water quality variables (T, ECw, DO, SO_4^{2-} , Na^+K^+ , Mg^{2+} , Ca^{2+} , NO_3^- , TP) and the discharge for the period 1980–1997 were selected for this analysis. In this paper a) the time series of monthly values of water quality parameters and the discharge were analysed using statistical methods, b) the existence of trends and the evaluation of the best fitted models were performed and c) the relationships between concentration and loads of constituents both with the discharge were also examined. Boxplots for summarising the distribution of a data set were used. The χ^2 -test and the Kolmogorov-Smirnov test were used to select the theoretical distribution which best fitted the data. Simple regression was used to examine the concentration-discharge and the load-discharge relationships. According to the correlation coefficient (r) values the relation between concentrations and discharge is weak ($r < 0.592$) while the relation between loads and discharge is very strong ($r > 0.902$). Trends were detected using the nonparametric Spearman's criterion upon the data for the variables: Q, ECw, DO, SO_4^{2-} , Na^+K^+ and NO_3^- on which temporal trend analysis was performed.

Key words: Strymon river, water quality, discharge, concentration, load, statistics, trends

Introduction

The water quality of water resources is a subject of ongoing concern. The assessment of long-term water quality changes is also a challenging problem. During the last decades, there has been an increasing demand for monitoring water quality of many rivers by regular measurements of various water quality variables. The result has been the gradual accumulation of reliable long-term water quality records and the examination of these data for long-term trends (Hirsch *et al.*, 1991). According to Liebetrau (1979), some of the necessities of water quality monitoring are the following: 1) to provide a system-wide synopsis of water quality, 2) to monitor long-range trends in selected water quality parameters, 3) to detect actual or potential water quality problems; if such problems exist 3a) to determine specific causes and 3b) to assess the effect of any convective action and 4) to enforce standards.

Computer systems now offer the possibility of handling and manipulating very large databases in ways which were not previously a practical option. Littlewood *et al.* (1998) have used such databases for estimation of UK river mass loads of pollutants. Miller and Hirst (1998) used the hydrochemical databases from an upland catchment in Scotland for a period of five years to assess the annual variation in amounts and concentration of solutes and to examine the variation in streamwater quality due to changes in flow, season and long time trend. Ferrier *et al.* (2001) analysed in detail databases for Scotland and identified temporal changes in water quality over the last 20 years.

The Strymon River is one of the most important rivers in the Greek and Balkan area, with an extensive basin of 17,330 km². The water quality and the discharge entering Greece is affected by many different anthropogenic factors and processes taking place in that part of the river catchment

occupied by Bulgaria and FYROM. Monthly measurements of the discharge and the water quality variables have been monitored at the Sidirokastro Bridge station of the Strymon River by the Greek Ministry of Agriculture. The Sidirokastro Bridge station is 10 km downstream of the Greek–Bulgarian border and upstream of Kerkini Lake, which is one of the significant wetlands in the area of Balkans.

This paper examines statistically: (1) the time series of monthly values of water quality parameters and the discharge at Sidirokastro station, (2) the existence of trends and the evaluation of the best fitted trend models, and (3) the relationships between concentration and loads of solutes and the discharge.

Methodology for the analysis of water quality parameters

In planning control and management programme of streams, the statistical and trend analysis as well as the relations between concentrations or loads and discharge are important steps for understanding the behaviour and the variation of water quality parameters and streamflow. This variation is affected by many factors. These factors may be formed by the different substances in the surface water due to activities in the catchment and may be further obscured by random events. Furthermore, the streamflow data exhibit hydrological persistence and seasonal variance (Antonopoulos and Papamichail, 1991).

PROBABILITY DISTRIBUTION OF WATER QUALITY PARAMETERS

Water quality data do not usually follow convenient probability distributions such as the well-known normal and lognormal distributions on which many classical statistical methods are based (Lettenmaier *et al.*, 1991).

Probability plots are used to determine how well data fit a theoretical distribution. This could be achieved by comparing visually histograms of measured values to the density curve of theoretical distributions.

To select the distribution which provided the best fit, ten theoretical probability distribution functions were examined: Chi-square (χ^2), Erlang (Er), Exponential (Ex), F, Gamma (G), Logistic (L), Lognormal (LN), Normal (N), Triangular (Tr) and Weibull (W). To select the distribution which fitted the data best, the χ^2 -test and the Kolmogorov-Smirnov test (K-S) were used.

The χ^2 test compares the measured and the predicted frequencies and it is described by the formula (Haan, 1977)

$$\chi^2 = \sum_{i=1}^k \left[\frac{(o_i - e_i)^2}{e_i} \right] \quad (1)$$

where o_i and e_i are the measured and predicted frequencies respectively and k is the number of class intervals. The null hypothesis H_0 is that the data follow a theoretical distribution. H_0 should be rejected if the statistic χ^2 exceeds the $(1-\alpha)$ quantile of a chi-square distribution having $(k-1)$ degrees of freedom.

The K-S test is a non-parametric test (Haan, 1977) of the fitting of data to a theoretical distribution using the maximum absolute deviation (D) between the two functions of cumulative distribution. It is calculated by

$$D = \max F_n(x) - F_0(x) \quad (2)$$

where $F_n(x)$ is the cumulative density function based on n measurements, $F_0(x)$ is the specified theoretical cumulative distribution function under the null hypothesis H_0 . The values of $D(n, \alpha)$ are given in tables (Haan, 1977). If $D \geq D(n, \alpha)$, the H_0 hypothesis is rejected and if $D < D(n, \alpha)$, H_0 is accepted, for the chosen level of significance $\alpha=0.05$.

SOLUTE CONCENTRATIONS-DISCHARGE AND LOADS-DISCHARGE RELATIONSHIPS

The concentrations of solutes in water in a stream vary during time. A major source of this variation is the stream discharge (Edwards, 1973; Pinol *et al.*, 1992). A strong relationship between streamwater chemistry and discharge at different spatial and temporal scales has been identified for rivers and streams (Larsen *et al.*, 1999).

The load (or flux) of water solutes (the product of discharge and concentration) is an important variable of water quality if interest focuses upon storage of the water and its constituents. The load of relatively conservative constituents may be important where the monitoring station is upstream of a reservoir, lake or estuary where the water has a long residence time and the exposure to chemicals by aquatic organisms or populations that ingest the water is of concern (Hirsch *et al.*, 1991).

Different models were proposed to describe the relationship between concentration-discharge and load-discharge (Edwards, 1973; Osborne *et al.*, 1980; Pinol *et al.*, 1992). These relationships give information on the variation of quality parameters due to discharge. Hirsch *et al.* (1982) suggested that, for water quality variables that are highly dependent on stream flow, the confounding effects of discharge variations be removed by analysing the residuals from a discharge-concentration relationship for trend, rather than the raw data. For this analysis, the linear ($C_{ij}=a+bQ_j$), the power ($C_{ij}=aQ_j^b$), the exponential ($C_{ij}=a \exp(bQ_j)$), and the logarithmic ($C_{ij}=a+b \ln(Q_j)$) models were used. The method of least squares for the pairs of monthly measured

values of each variable and the discharge was used to determine the constants of these models.

TREND ANALYSIS

Testing water quality data for trend over a period of time has received considerable attention recently. The interest in methods of water quality trend arises for two reasons. The first is the intrinsic interest in the question of changing water quality arising out of the environmental concern and activity. The second reason is that only recently has there been a substantial amount of data that is amenable to such an analysis.

Trend analysis determines whether the measured values of a water quality variable increase or decrease during a time period. In statistical terms, has the probability distribution from which they arise changed over time? It would be useful to describe the amount or rate of that change, in terms of changes in some central value of the distribution such as mean or median (Hirsch *et al.*, 1982; Hirsch and Slack, 1984).

Hirsch *et al.* (1982) suggested an adaptation of the Kendall non-parametric test to detect trends in seasonally varying water quality time series; this is often referred to as the seasonal Kendall's test. This test can accommodate time series with missing data. In this study, to detect the existence of trends in the time series of the variables involved, the nonparametric Spearman's criterion was used and different trend models were fitted (Dahmen and Hall, 1990). The Spearman rank-correlation coefficient is described as:

$$R_{sp} = 1 - \frac{6 \sum_{i=1}^n (D_i D_i)}{n(n^2 - 1)} \quad (3)$$

where n is the total number of values in each time series, D is the difference and i is the chronological order number. The difference between rankings is computed as $D_i = Kx_i - Ky_i$, where: Kx_i is the rank of a measured variable in chronological order and Ky_i is the series of measurements transformed to its rank equivalent, by assigning the chronological order number of a measurement in the original series to the corresponding order number in the ranked series, y . The null hypothesis, $H_0: R_{sp} = 0$ (there is no trend), against the alternate hypothesis, $H_1: R_{sp} < 0$ or > 0 (there is a trend), is checked with the test statistic:

$$t_t = R_{sp} \left[\frac{n-2}{1-R_{sp}^2} \right]^{0.5} \quad (4)$$

where t_t has Student's t -distribution, with $v=n-2$ degrees of freedom. At a significant level of 5%, the time series has no

trend if:

$$t\{v, 2.5\% \} < t_t < t\{v, 97.5\% \}, \quad (5)$$

The trend analysis applied here was an attempt to fit the following linear, quadratic, exponential and mixed type models to the time series of the discharge and the water quality parameters:

$$F = \alpha + \beta \cdot T \quad (6)$$

$$F = \alpha + \beta \cdot T + c \cdot T^2 \quad (7)$$

$$F = \exp(\alpha + \beta \cdot T) \quad (8)$$

$$F = \exp(\alpha + \beta/T) \quad (9)$$

The best-fitted model of time trend for each variable was chosen using the following statistical criteria of Mean Error (ME), Mean Square Error (MSE), Mean Absolute Error (MAE) and Mean Absolute Percent Error (MAPE) (Makridakis *et al.*, 1986):

$$ME = \sum_{i=1}^n e_i / n \quad (10)$$

$$MSE = \sum_{i=1}^n e_i^2 / n \quad (11)$$

$$MAE = \sum_{i=1}^n |e_i| / n \quad (12)$$

$$MAPE = \sum_{i=1}^n |(X_i - F_i / X_i) \cdot 100| / n \quad (13)$$

where X_i is the measured value at time i , F_i is the predicted value at the same time, $e_i = X_i - F_i$ and n is the number of measurements. The closer the average ME is to zero and the smaller the values of MSE, MAE and MAPE, the better the model fits the time-series (Statgraphics, 1987).

DESCRIPTION OF STUDY SITE

The Strymon River, is a transboundary river of Greece, Bulgaria and FYROM. Its length is about 392 km and after a distance of approximately 118 km in Greek territory it discharges into the Northern Aegean Sea (Fig. 1). The total area of the Strymon catchment is approximately 17,330 km² of which 8,670 km² (50%) are in Bulgaria, 2,365 km² (13.6%) in FYROM and 6,295 km² (36.4%) in Greece. The mean elevation of the catchment is approximately 830 m while 77 km upstream of the mouth of the Strymon River a dam was constructed in 1932 forming Kerkini Lake, which is one of the 11 Ramsar sites in Greece. The initial volume of Kerkini Lake was 312×10⁶ m³, which had reduced to



Fig. 1. River Strymon, its catchment boundaries and Sidirokastró water quality sampling station

170×10⁶ m³ in 1977. In 1983 a new dam was constructed in the same place. Now the maximum volume of lake rises to 600×10⁶ m³. The main attributes of the lake are flood control, irrigation, fisheries and biodiversity. The Strymon River carries high quantities of sediments and solutes into the lake, affecting the system values negatively.

The mean yearly precipitation in the area of Kerkini lake is 534 mm, with a distribution during the year which follows the two characteristic peaks of a Mediterranean climate. The mean yearly temperature is 15.4 °C, with July the warmest month (26.7 °C) and January the coldest month (3.9 °C).

Upstream of Kerkini Lake and 10 km downstream of the Greek–Bulgarian border at Sidirokastró Bridge of the Strymon River there is a monitoring station, where the Greek Ministry of Agriculture measures water flow and takes water samples once every month. This station has been included in the European Community's water quality monitoring programme since 1982 (E.C., 1994).

Among the variables measured by the Department of Irrigation and Water Protection of the Greek Ministry of Agriculture at the Sidirokastró Bridge station are water temperature (T), pH, specific conductivity (EC_w), dissolved

oxygen (DO), bicarbonates (HCO₃⁻), sulphates (SO₄²⁻), chlorides (Cl⁻), sodium and potassium (Na⁺+K⁺), magnesium (Mg²⁺), calcium (Ca²⁺), nitrate (NO₃⁻), ammonia (NH₄⁺), total phosphorus (TP) and discharge (Q). The monitoring data for these variables available for the analysis as presented in this paper is on a monthly basis for the period 1980–1997. Discharge is a parameter with many missing values, especially since 1989. It was impossible to complete the values for discharge since 1994 and for this reason, the relationship between discharge and the concentrations and loads were examined only for the period 1980 to 1993. Neither nitrate nor total phosphorus have been measured since 1993. The missing monthly values were completed using the methods proposed by Holder (1985).

Results and discussion

STATISTICAL ANALYSIS OF WATER QUALITY PARAMETERS AND DISCHARGE

Figure 2 shows the time series of monthly measured values of Q, T, EC_w, concentrations of DO, SO₄²⁻, Na⁺+K⁺, Mg²⁺, Ca²⁺, NO₃⁻ and TP, at Sidirokastró station. The statistical measures of time series of water quality variables at the Sidirokastró station, used in the following analysis, are given in Table 1. In Table 1, the statistical measures of pH, Cl⁻, HCO₃⁻ and NH₄⁺ parameters are also given. Many water quality parameters show striking seasonal variations. For temperature and dissolved oxygen, seasonal variation is relatively uniform during the time. There is also a variation in concentrations and discharge. There are different reasons for these variations. Some of them depend on discharge and seasonality; the magnitudes of the fluctuations in discharge are much greater than those of concentrations. The ratio of highest to lowest concentration and water discharge is very large for discharge (214:1) followed by total phosphorus (63:1), sulphate (47:1), temperature (27:1), Mg²⁺ (19:1) and NO₃⁻ (13.6:1). There is low ratio for Na⁺+K⁺ (6.5:1), Ca²⁺ (3.5:1), EC_w (3.3:1) and DO (2.4:1). The dominant anion and cation in the water of Strymon river is HCO₃⁻ and Ca²⁺, respectively. The values of NO₃⁻ show anthropogenic influence but it is five times less than those in the European rivers in which the medium level of NO₃⁻ is 20 mg l⁻¹ (Maybeck *et al.*, 1989). The mean value of phosphorus coincides with the critical value of 0.15 mg l⁻¹ which is considered a minimum requirement for the avoidance of eutrofication effects on European rivers (van Dijk *et al.*, 1994).

A very useful and concise graphical display for summarising the distribution of a data set is the boxplot (Helsel and Hirsch, 1992). Boxplots provide visual

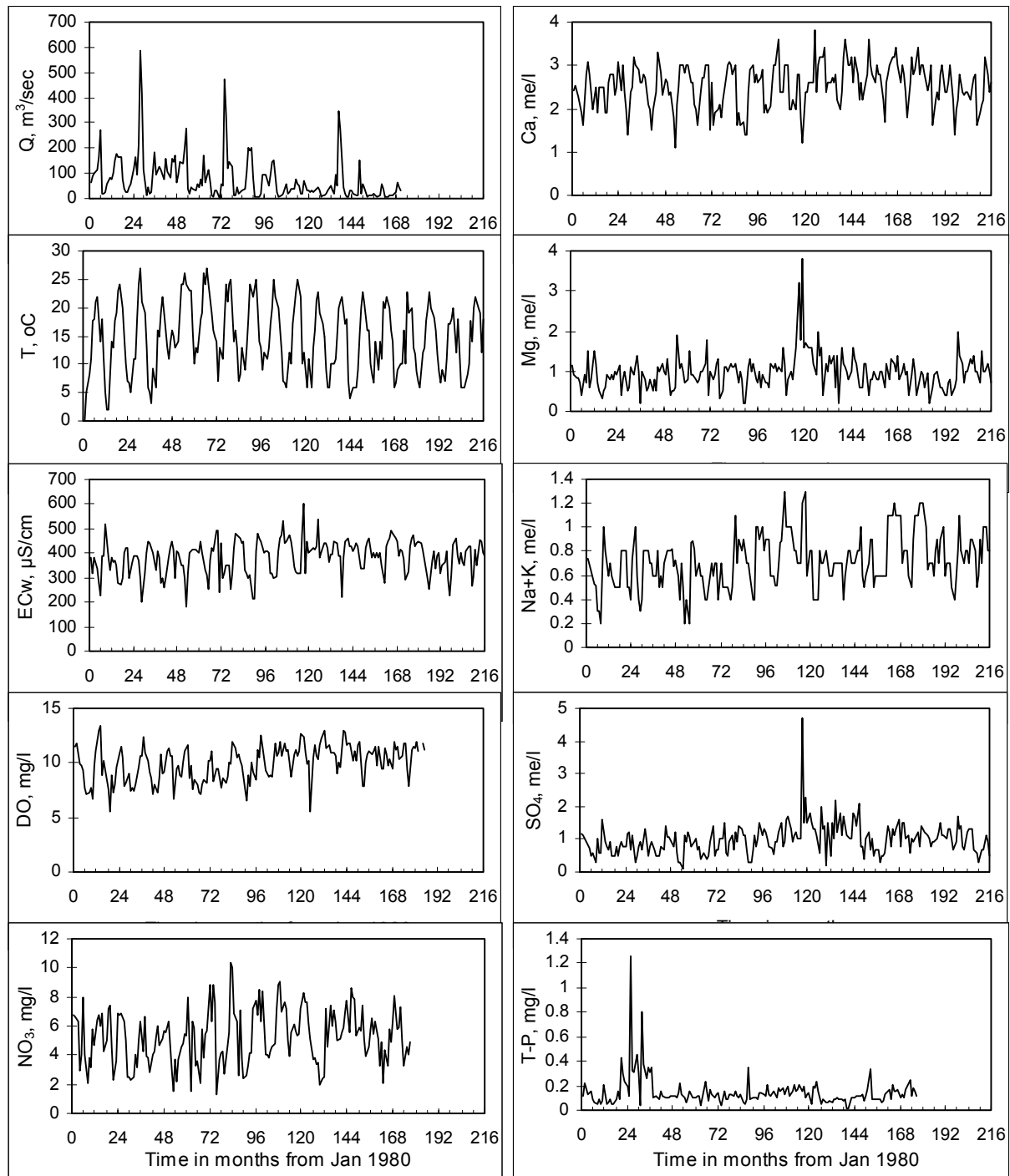


Fig. 2. Time series of water quality parameters and discharge at Sidirokastró station of the Strymon River

summaries of (1) the centre of the data (the median = the centre line of the box), (2) the variation or spread (interquartile range=the box height), (3) the skewness (quartile skew=the relative size of box halves) and (4) presence or absence of unusual values (“outliers” and “extreme” values). Boxplots are even more useful in comparing these attributes between several data sets.

Figure 3 shows the boxplots of water quality parameters and discharge at Sidirokastró station (Mitsiou *et al.*, 1999). The boxplots show that the data of the variables of Q , EC_w , SO_4^{2-} , Na^+K^+ , Mg^{2+} , Ca^{2+} , and TP depart from a normal distribution not only in skewness, but also by the number of outliers and the extreme values. The data of the variables DO and NO_3^- depart from a normal distribution only in the

Table 1. Statistical parameters of the time series of monthly values of water quality parameters and discharge of the Strymon River at Sidirokastro station.

<i>Variable</i>	<i>Sample Size</i>	\bar{x}	δ	x_{max}	x_{min}	$x_{max} - x_{min}$	<i>s</i>	<i>CV</i>
Q, m ³ sec ⁻¹	171	76.43	46.00	588.87	2.75	586.12	86.96	113.77
T, °C	216	14.65	14.00	27.00	0.00	27.00	6.14	41.87
ECw, µS cm ⁻¹	216	383.19	400.00	600.00	180.00	420.00	68.65	17.92
DO, mg l ⁻¹	182	9.95	10.16	13.44	5.5	7.94	1.61	16.17
SO ₄ ²⁻ , me l ⁻¹	216	0.99	1.00	4.70	0.10	4.60	0.46	46.73
Na ⁺ + K ⁺ , me l ⁻¹	216	0.72	0.70	1.30	0.20	1.10	0.21	29.86
Mg ²⁺ , me l ⁻¹	216	0.97	1.00	3.80	0.20	3.60	0.43	44.79
Ca ²⁺ , me l ⁻¹	216	2.52	2.60	3.80	1.10	2.70	0.50	19.81
NO ₃ ⁻ , mg l ⁻¹	177	5.25	5.28	10.34	0.76	9.58	1.88	35.81
TP, mg l ⁻¹	177	0.15	0.12	1.26	0.02	1.24	0.12	83.90
pH	215	7.79	7.85	8.5	6.9	1.6	0.37	4.75
Cl ⁻ , me l ⁻¹	215	0.25	0.2	0.8	0.1	0.7	0.15	60.00
HCO ₃ ⁻ , me l ⁻¹	215	2.92	3.0	4.2	1.3	2.9	0.59	20.21
NH ₄ ⁺ , mg l ⁻¹	110	0.113	0.086	0.56	0.025**			

Notes on the table: \bar{x} : mean, δ : median, x_{max} : maximum value, x_{min} : minimum value, *s*: standard deviation, *CV*: coefficient of variation, ** Lower detection limit.

skewness. It is noted that only temperature is approaching normality. Figure 3 shows that there are many outliers and extreme values for the variables of Q, SO₄²⁻, Mg²⁺, and TP. The extreme values of Q are due to floods, while the extreme values of other variables are unexpected and maybe due to non-suitable measurements or handling the water samples.

The procedure used to fit a theoretical continuous distribution function to the data time series (a) provides the parameter estimates for the chosen distribution function, (b) calculates a chi-square statistic that allows comparison of

observed and expected frequencies, with its degrees of freedom (d.f.) at a chosen significant level of $\alpha=0.05$, (c) runs a Kolmogorov-Smirnov one-sample test for goodness-of-fit with its maximum absolute deviation (D) and (d) plots a frequency histogram with the fitted distribution superimposed on it (Statgraphics, 1987). Table 2 includes the results of the aforementioned procedure for the water variables of the Strymon River. It has been accepted that the best fitted theoretical distribution to each data time series is the one which satisfies both tests (χ^2 -test and K-S test).

Table 2. The best-fitted distribution parameters and the values of the goodness-of-fit tests

<i>Variable</i>	<i>Distribution</i>	<i>Distribution parameters</i>		χ^2 -test		<i>K-S-test</i> D
				χ^2	d.f.	
Q, m ³ sec ⁻¹	Weibull	α : 0.9955 β : 76.269		2.635	4	0.0748
T, °C	Normal	μ : 14.6545 σ : 6.13597		36.9328	12	0.0755
ECw, µS cm ⁻¹	Weibull	α : 6.43361 β : 410.991		10.3065	9	0.0796
DO, mg l	Weibull	α : 7.31446 β : 10.6215		11.0878	8	0.0542
SO ₄ ²⁻ , me l ⁻¹	Gamma	α : 5.09018 β : 5.12012		4.44135	3	0.07735
Na ⁺ + K ⁺ , me l ⁻¹	Weibull	α : 3.64018 β : 0.79519		13.5527	7	0.119063
Mg ²⁺ , me l ⁻¹	Logistic	μ : 0.944792 σ : 0.39549		9.34	2	0.08544
Ca ²⁺ , me l ⁻¹	Weibull	α : 5.88114 β : 2.72124		9.476	8	0.07423
NO ₃ ⁻ , mg l ⁻¹	Weibull	α : 3.07478 β : 5.87368		6.8811	9	0.04016
TP, mg l ⁻¹	LogNormal	μ : 0.143282 σ : 0.08597		15.389	4	0.092852

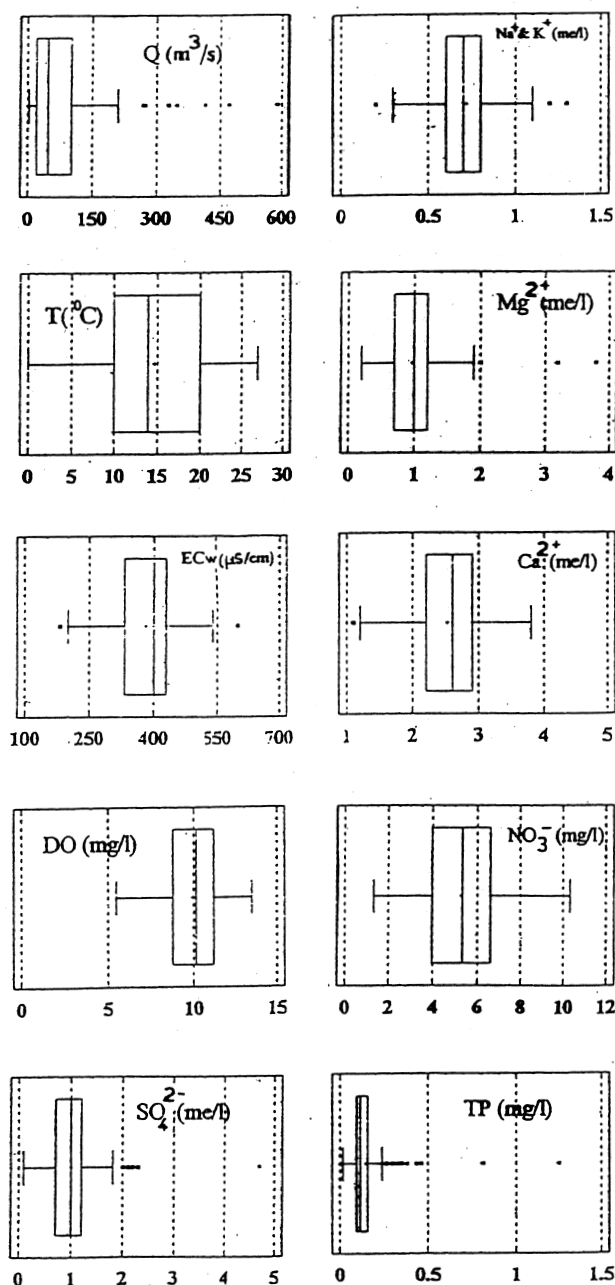


Fig. 3. Boxplots of measured values of water quality parameters and discharge at Sidirokastro station of the Strymon River

Figure 4 shows the frequency histograms of the data time series with the best fitted distributions.

After a thorough examination of the statistical tests' parameter values the following conclusions about the distribution of each variable were reached: the Strymon's discharge follows the Weibull distribution. The specific conductivity, the dissolved oxygen, the Ca^{2+} and the nitrate also follow the Weibull distribution. The sulphates follow the Gamma distribution. Water temperature, Mg^{2+} and total phosphorus approach none of the known theoretical

distributions according to both goodness-of-fit criteria. According to the K-S test only, water temperature approaches the normal distribution, Mg^{2+} the logistic and total phosphorus the lognormal. According to the χ^2 -test only $\text{Na}^+ + \text{K}^+$ follows the Weibull distribution.

CONCENTRATION- DISCHARGE AND LOAD-DISCHARGE RELATIONSHIPS

The results of simple regression applied between each water quality variable's concentration (dependent variable) and the discharge (independent variable) as well as between each water quality variable's load (dependent variable) and the discharge (independent variable), monitored at the Sidirokastro station of the Strymon River are given in Table 3. In this table the values parameters a and b of linear ($C_{ij} = a + bQ_j$), power ($C_{ij} = aQ_j^b$), exponential ($C_{ij} = a \exp(bQ_j)$), and logarithmic ($C_{ij} = a + b \ln(Q_j)$) models as well as the correlation coefficients are given. Figures 5 and 6 show the best-fitted to the data regression models. From the values of Table 3 and the graphs of Figs. 5 and 6 it is clear that: (a) no one of the applied models describes well the concentration-discharge relationships or these relationships are very weak, (b) the correlation coefficients are negative for most of the variables, except nitrates and total phosphorus, which show a decreasing relationship. This is a result (Edwards, 1973) of dilution effects of surface runoff, during periods of high runoff in the catchment, on the water of base runoff, (c) the logarithmic and the power models describe better the concentration-discharge relationships, and d) the relationship between conductivity (which express the total dissolved solids) and discharge, has got the better correlation coefficient value ($r = -0.592$), following by Calcium ($r = -0.553$) and then by the other cations $\text{Na}^+ + \text{K}^+$ ($r = -0.466$) and Mg^{2+} ($r = -0.384$), while dissolved oxygen, total phosphorus and nitrates show weaker relations.

The load-discharge relationships show better correlation than that of concentration-discharge. The power model expresses better the load-discharge relationships. The correlation coefficients are very high: $r = 0.903$ and $r = 0.981$ for the cations Mg^{2+} and Ca^{2+} , respectively and $r = 0.941$ and $r = 0.902$ for nitrates and total phosphorus, respectively. The slope coefficient b (Table 3) for nitrate and phosphorus discharge-load relationships are greater than 1.0. The concentrations of these constituents have a fairly good positive correlation with discharge (Edwards, 1973). The dilution effects of high discharges on concentration produces lower values for coefficient b . The smaller value of b is 0.83 for Mg^{2+} , followed by 0.89 for Ca^{2+} .

Discharge has strong seasonality with the higher values during the spring as a result of snow melting from the

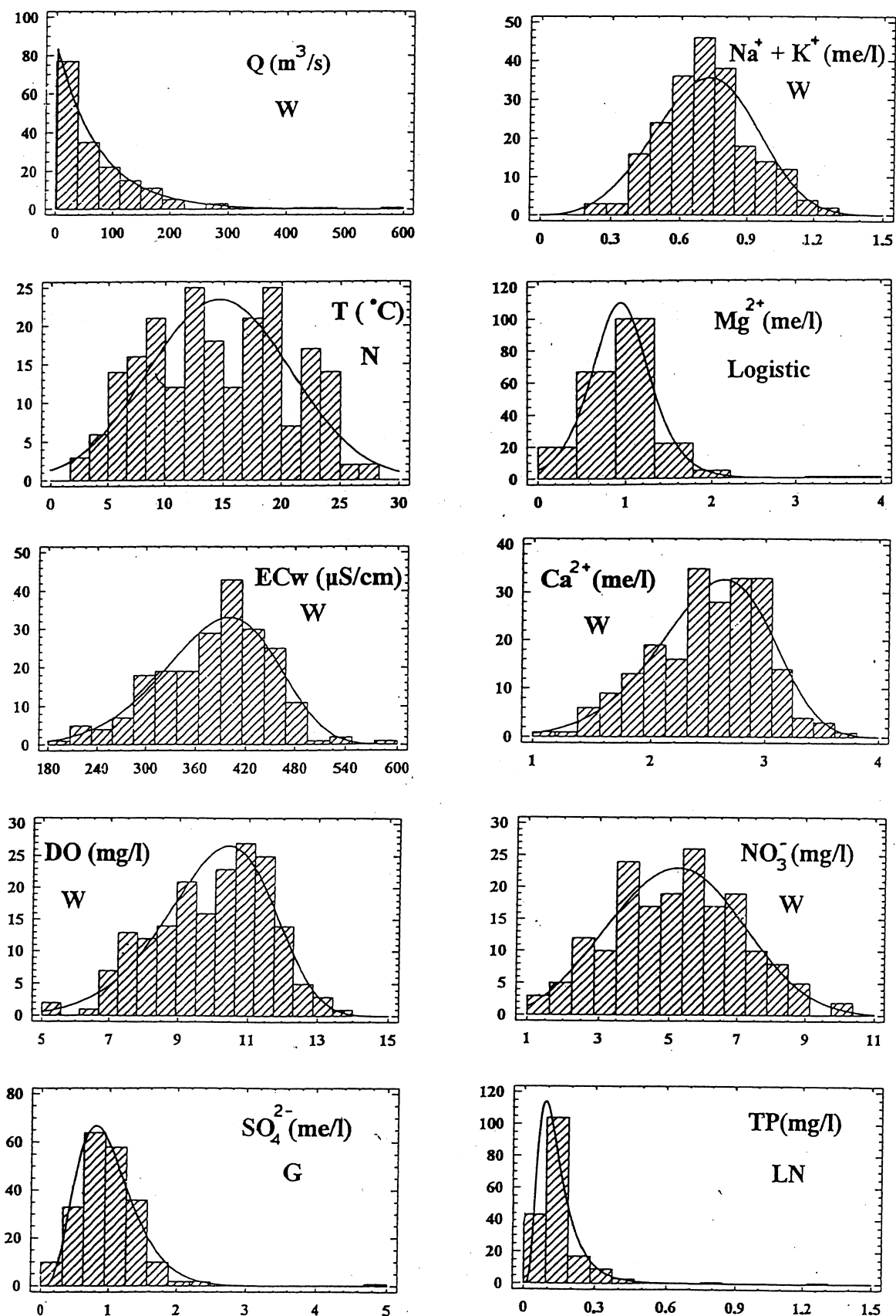


Fig. 4. Frequencies of monthly measured values of water quality parameters and discharge with the best fitted theoretical distribution

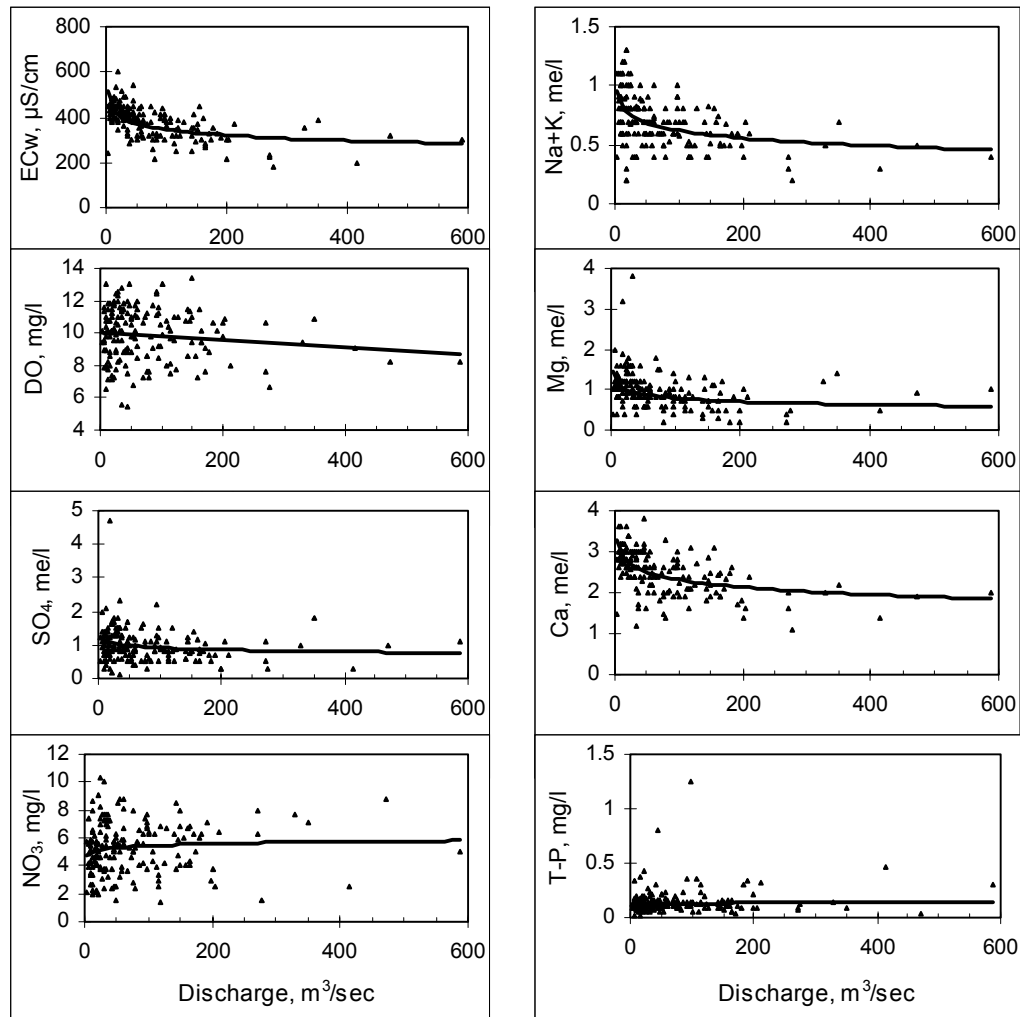


Fig. 5. Concentration of water quality parameters against discharge relationships with the curve of the best fitted model.

Table 3. Concentration-discharge and load-discharge relationships

Concentration-discharge					Load-discharge				
Variable	Equation	a	b	r	Variable	Equation	a	b	r
ECw, μS	Power	573.39	-0.1101	-0.592					
DO, mg l^{-1}	Linear	10.07	-0.0023	-0.123	DO, tn d^{-1}	Power	0.8635	0.9936	0.987
SO_4^{2-} , me l^{-1}	Log	1.3267	-0.0883	-0.190	SO_4^{2-} , tn d^{-1}	Power	5.0192	0.9173	0.895
$\text{Na}^+ + \text{K}^+$, me l^{-1}	Log	1.0428	-0.0918	-0.466					
Mg^{2+} , me l^{-1}	Power	1.6882	-0.1651	-0.384	Mg^{2+} , tn d^{-1}	Power	1.7732	0.8349	0.903
Ca^{2+} , me l^{-1}	Log	3.5294	-0.263	-0.553	Ca^{2+} , tn d^{-1}	Power	6.5012	0.8898	0.981
NO_3^- , mg l^{-1}	Log	4.5466	0.1961	0.113	NO_3^- , tn d^{-1}	Power	0.3717	1.0354	0.941
TP, mg l^{-1}	Power	0.0916	0.0746	0.144	TP, tn d^{-1}	Power	0.0079	1.0746	0.902

mountainous area of the catchment. The seasonality in discharge and the inverse relationships with the solutes of Ca^{2+} and Mg^{2+} , which have groundwater sources and

$\text{Na}^+ + \text{K}^+$, which have predominantly point sources, controls the patterns of these solutes. TP and NO_3^- show no well-defined seasonal patterns with very highly scattered

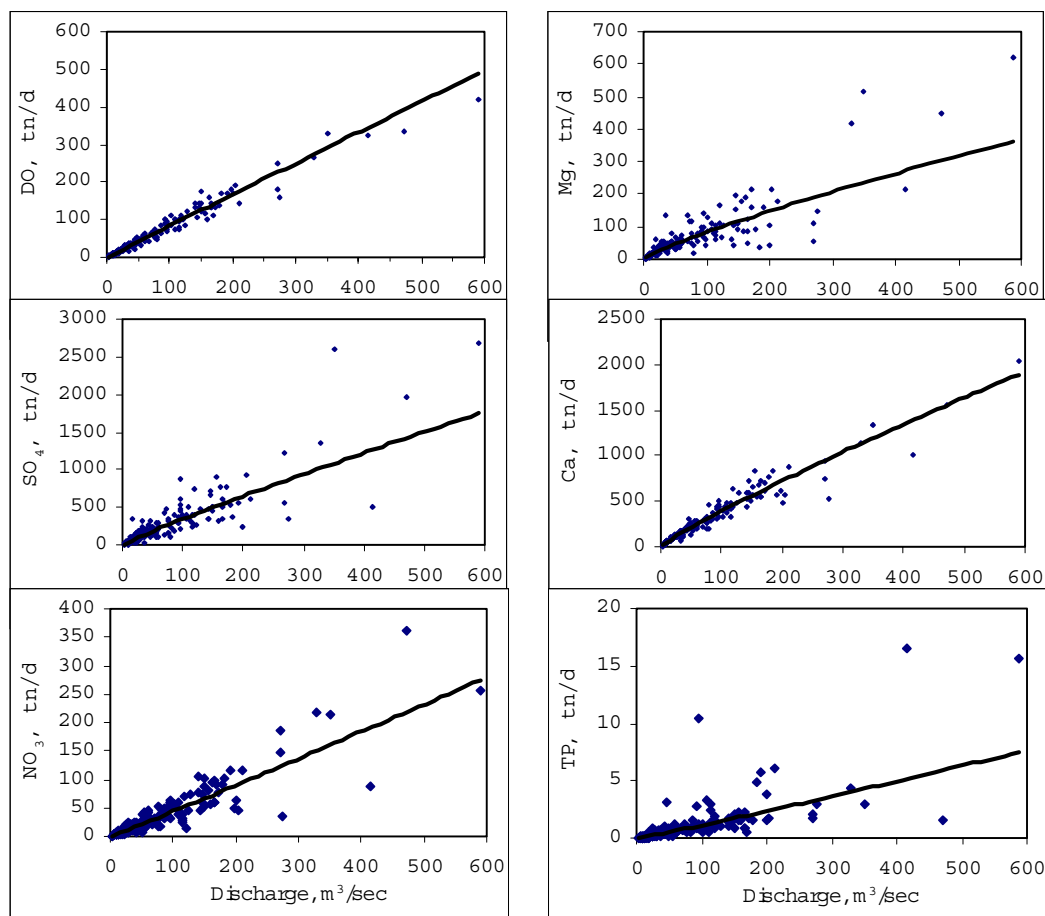


Fig. 6. Load of water quality parameters against discharge relationships with the curve of the best fitted model.

relationships with the water discharge, indicating the existence of many different potential sources and availability of sources for transportation within the river system.

TREND ANALYSIS OF WATER QUALITY PARAMETERS

The time series of nine water quality parameters and the discharge of the Strymon River at the Sidirokastrò station were tested for existence of trend, by using the nonparametric Spearman's criterion and analysed by fitting different trend models. The value of Spearman's rank-correlation coefficient (Eqn. 3), the Spearman statistical criterion (Eqn. 4) and the limits defined by Eqn. (5), which for $n=216$ (18 years*12 months), is: $t_{\{214,2.5\%\}} < t_i < t_{\{214, 97.5\%\}}$, where: $t_{\{214,2.5\%\}} = -1.96$ and $t_{\{214,97.5\%\}} = 1.96$, for the examined time series are given in Table 4. So, according to the results of Spearman's test (Table 4), the values of the given series of observations of Q , ECw , DO , SO_4^{2-} , $Na^+ + K^+$ and NO_3^- changed over time in a certain rate. In order to describe these changes an attempt

was made to fit one of the known trend models (Eqns. 6-9) to each data time series. The selection of the "best-fitted" model was based on the values of the statistical tests described by Eqns. 10-12 and are given in Table 5, while

Table 4. Detecting trend existence in Strymon's water quality variables

Variable	Sidirokastrò station		Is there a trend?
	R_{sp}	t_i	
Q , $m^3 \text{ sec}^{-1}$	-0.4940	-7.386	Yes
ECw , $\mu S \text{ cm}^{-1}$	0.1885	2.808	Yes
DO , $mg \text{ l}^{-1}$	0.4145	6.111	Yes
SO_4^{2-} , $me \text{ l}^{-1}$	0.2657	4.031	Yes
$Na^+ + K^+$, $me \text{ l}^{-1}$	0.3324	5.156	Yes
Mg^{2+} , $me \text{ l}^{-1}$	0.1106	1.628	No
Ca^{2+} , $me \text{ l}^{-1}$	0.1311	1.935	No
NO_3^- , $mg \text{ l}^{-1}$	0.1551	2.077	Yes
TP , $mg \text{ l}^{-1}$	-0.0475	-0.629	No

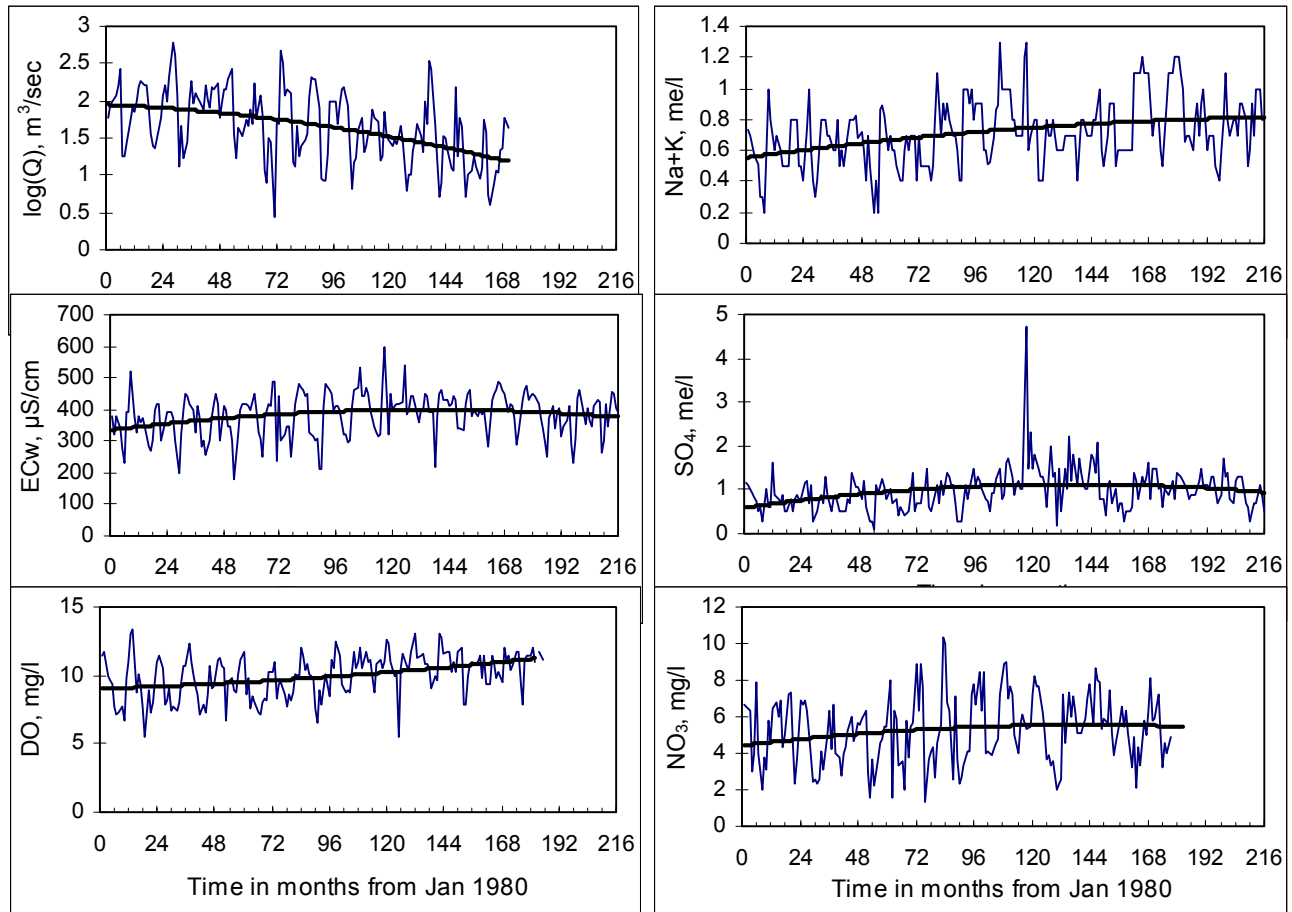


Fig. 7. Monthly measured values of water quality parameters and discharge and the curves of the best fitted trend model.

their graphs, along with the observed values of the data time series, are shown in Fig. 7 (Mitsiou *et al.*, 2000).

The conclusions deriving from the previous trend analysis are: (a) the second order equation (Eqn. 7) describes the trend of the data time series better, (b) the trend of discharge (Q) is downwards, while the trends of the water quality variables (ECw and concentration of DO, SO_4^{2-} , Na^+K^+ and NO_3^-) are upwards, and c) the concentrations of Ca^{2+} ,

Mg^{2+} and TP have no trends.

The downward trend of discharge in relation to the relatively high inverse relationship with ECw and Na^+K^+ (Table 3) has affected the trend of these variables. The decrease in discharge causes increase in these variables, while the weak relationship of discharge with DO, SO_4^{2-} , NO_3^- and TP does not influence the trend of these variables.

The year 1989 was a very significant historical year in

Table 5. Trend models which describe better the trends of the Strymon's water quality variables, with the values of the statistical tests for the goodness-of-fit

Variable	Model	ME	MSE	MAE	MAPE
Log Q	$4.49932 - 3.42274\text{E-}3\text{*T} - 4.08985\text{E-}5\text{*T}^2$	0.00	0.88218	0.74856	23.8301
ECw	$334.772 + 0.953291\text{*T} - 3.51276\text{E-}3\text{*T}^2$	0.00	4,399.69	53.1991	15.5431
DO	$9.04276 + 5.59813\text{E-}3\text{*T} + 3.55885\text{E-}5\text{*T}^2$	0.00	2.1618	1.18056	12.7407
SO_4^{2-}	$0.588238 + 7.95705\text{E-}3\text{*T} - 2.92094\text{E-}5\text{*T}^2$	0.00	0.19436	0.30573	43.8443
$\text{Na}^+ + \text{K}^+$	$0.553699 + 2.13343\text{E-}3\text{*T} - 4.31444\text{E-}6\text{*T}^2$	0.00	0.03990	0.16147	26.6884
NO_3^-	$4.4258 + 0.015875\text{*T} - 5.60225\text{E-}5\text{*T}^2$	0.00	3.41646	1.51484	39.6041

the countries of upstream boundaries of Greece. It was the year with very drastic changes in the political status of Bulgaria and FYROM. The transition from the socialist to the free market status influenced the development of these countries. It is very important to study the trends in the flow and water quality of the Strymon river entering Greece during these two special periods: before the political change and after it. The examination of time series for the period of 1980 to 1989 shows that, except discharge, all the other parameters presented an upward trend. The explanation, in relation to the political status, is that the countries were in a development stage and they were likely to use the water from the river and to produce solutes that pollute the river. During the last period (1990–1997) the upstream countries have been under a stagnation and retardation growth status by stopping or reversing productivity, especially during the first years of the decade. The time series during this period show a continuous decrease in discharge, ECw and NO_3^- , while there is an increase in the DO, Na^+K^+ and SO_4^{2-} .

Conclusions

Data of water quality variables and discharge at the Sidirokastro station of the transboundary Strymon River in its Greek part were analysed using statistical methods and trend analysis. The time series of monthly measured values of six water quality variables (ECw, T, SO_4^{2-} , Na^+K^+ , Mg^{2+} and Ca^{2+}) over 18 years (1980–1997), and the discharge (Q), DO, NO_3^- and TP over 14 years (1980–1993) are used for this analysis.

The statistical analysis of aforementioned variables resulted that according to the K-S and χ^2 tests, discharge, specific conductivity, dissolved oxygen, Ca^{2+} and the nitrate follow the Weibull distribution, while sulphates follow the Gamma distribution. According to the K-S test only, water temperature approaches the normal distribution, Mg^{2+} the logistic and total phosphorus the Lognormal, while Na^+K^+ follows the Weibull distribution according to the χ^2 -test only.

Seasonal variations in stream water chemistry are strongly related to discharge variations. However, the solute concentrations were related weakly with the discharge although the solute loads were related very strongly with the discharge.

The nonparametric Spearman's criterion was used to analyse for trends in the water quality variables and discharge time series, for the period 1980 to 1997. The Spearman's test detected trends in discharge, dissolved oxygen, conductivity, sulphate, sodium, potassium and nitrate. The second order equation provided a better description of variables for which trends were detected.

Discharge was the only variable which showed a downward trend.

Acknowledgements

The authors wish to thank the Department of Irrigation and Water Protection of Greek Ministry of Agriculture for providing the water quality and discharge monitoring data for the Strymon River.

References

- Antonopoulos, V. and Papamichail, D., 1991. Stochastic analysis of water quality parameters in streams, In: *Water Resources Management and Technology*, G. Tsakiris (Ed.). Balcema, 369–376.
- Dahmen, E.R. and Hall, M.J., 1990. *Screening of Hydrological Data: Tests for Stationarity and Relative Consistency*, ILRI Publication No.49, Wageningen, The Netherlands.
- Edwards, A.M.C., 1973. The variation of dissolved constituents with discharge in some Norfolk rivers, *J. Hydrol.*, **18**, 219–242.
- European Community, 1994. *Water Quality of Surface Waters-Common procedure for exchange of information*. General Direction XI, Environment, nuclear safety and public protection.
- Ferrier, R.C., Edwards, A.C., Hirst, D., Littlewood, I.G., Watts, C.D. and Morris, R., 2001. Water quality of Scottish rivers: spatial and temporal trends, *Sci. Total Envir.*, **265**, 327–342.
- Haan, C.T., 1977. *Statistical methods in hydrology*. The Iowa University Press, Iowa, U.S.A.
- Helsel, D.R. and Hirsch, R.M., 1992. *Statistical Methods in Water Resources*. Elsevier, The Netherlands.
- Hirsch, R.M. and Slack, J.R., 1984. A nonparametric trend test for seasonal data with serial dependence, *Water Resour. Res.*, **20**, 727–732.
- Hirsch, R.M., Slack, J.R. and Smith, R.A., 1982. Techniques of trend analysis for monthly water quality data, *Water Resour. Res.*, **18**, 107–121.
- Hirsch, R. M., Alexander, R.B. and Smith, R.A., 1991. Selection of methods for the detection and estimation of trends in water quality, *Water Resour. Res.*, **27**, 803–813.
- Holder, R.L., 1985. *Multiple regression in Hydrology*. Institute of Hydrology, Wallingford, UK. 147pp.
- Larsen, S.E., Kronvang, B., Windolf, J. and Svendsen, L.M., 1999. Trends in diffuse nutrient concentrations and loading in Denmark: Statistical trend analysis of stream monitoring data, *Water. Sci. Technol.*, **39**, 197–205.
- Lettenmaier, R.P., Hooper, E.R., Wagener, C., and Fans, K.B., 1991. Trends in stream quality in continental United States, 1978–1987, *Water Resour. Res.*, **27**, 327–339.
- Liebetrau, A.M., 1979. Water quality sampling: some statistical considerations, *Water Resour. Res.*, **15**, 1717–1728.
- Littlewood, I.G., Watts, C.D. and Custance, J.M., 1998. Systematic application of United Kingdom river flow and quality databases for estimating annual river mass loads (1975–1994), *Sci. Total Envir.*, **210**, 21–40.
- Makridakis, S., Wheelwright, S.C. and Megee, V.E., 1986. *Forecasting: Methods and Application*, 2nd edition. Wiley, New York.
- Maybeck, M., Chapman, D. and Helmer, R., 1989. *Global Freshwater Quality - A First assessment*, WHO and UNEP, Blackwell Ltd., U.S.A., 306 pp.

- Miller J.D. and Hirst, D., 1998. Trends in concentrations of solutes in an upland catchment in Scotland, *Sci. Total Envir.*, **216**, 77–88.
- Mitsiou, K., Antonopoulos, V. and Papamichail, D., 1999. Statistical analysis of water quality parameters time series of Strymon river, *Hydrotechnika*, **9**, 59–74 (in Greek)
- Mitsiou, K., Antonopoulos, V. and Papamichail, D., 2000. *Trend analysis of water quality parameters of Strymon river*. Proceedings of 8th conference of Hellenic Hydrotechnical Chamber (EYE), Athens, 259–266 (in Greek).
- Oborne, A.C., Brooker, M.P. and Edwards, R.W., 1980. The chemistry of the River Wye, *J. Hydrol.*, **45**, 233–252.
- Pinol, J., Avila, A. and Roda, F., 1992. The seasonal variation of streamflow chemistry in three forested Mediterranean catchments, *J. Hydrol.*, **140**, 119–141.
- Statgraphics, 1987. *User's Guide. Statistical Graphics Corporation*, S.T.S.C., Inc., USA.
- van Dijk, G.M., van Lieke, L., Amiraal, W., Bannink, B.A. and Cappon, J.J., 1994. Present state of the water quality of European rivers and implications for management, *Sci. Total Envir.*, **145**, 187–195.

